

## TITLE OF THE INVENTION

Wall part acted upon by an impingement flow

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## BACKGROUND OF THE INVENTION

### Field of the Invention

The invention relates to an impingement flow for wall parts according to the preamble of patent claim 1.

Among the convective cooling and heating methods, the highest heat transmission coefficients can be achieved with impingement cooling and impingement heating respectively. The impingement flow is realized by virtue of the fact that a cooling or heating fluid (e.g. air, water, steam, hydrogen, liquid sodium, etc) flows through one or more orifices in a wall and strikes an opposite surface more or less perpendicularly. When striking the impingement area, the free jets are deflected and a flow forms parallel to the impingement area, as a result of which high heat transmission is achieved between flow and wall. To enlarge the heat-transmitting area, it is known to provide this area with roughness elements, mostly in the form of ribs.

### Discussion of Background

DE-A1 44 30 302 discloses impingement cooling of the type mentioned at the beginning. The method shown in said document is distinguished by a plurality of impingement tubes which are arranged areally with their inlet on a plane or curved carrier and are directed with their mouth toward the wall part to be cooled, the carrier being arranged at a distance from the wall part. In one exemplary embodiment (Fig. 3), the impingement area of the wall part to be cooled is designed as a relief, in which case the jets directly strike projecting humps. Thus, the inhomogeneous heat transmission in the impingement jets is to be

10002633-120501

compensated for and a homogeneous temperature distribution on the hot side of the wall part is to be achieved. In this arrangement, the humps are designed essentially as cylinders having rounded-off edges, which are brought about during manufacture. In a further exemplary embodiment (Fig. 4), the relief is present in the form of ribs. ~~Both geometrical forms have no advantageous thermal boundary conditions in relation to the heat transmission.~~ The heat, which can be dissipated via the surface of an element projecting from the wall to be cooled, must first of all be directed through the base area and the material to the surface. As a result, a thermal stratification occurs in the material of the element. Depending on material and geometrical form, this thermal stratification may result in the temperature difference between fluid and element becoming so small at the points furthest away from the base of the element that virtually no more heat transmission takes place.

Furthermore, extensive investigations relating to local heat transmission coefficients of individual impingement jets and zones of impingement jets on plane surfaces as well as on surfaces having simple curvature are known.

#### SUMMARY OF THE INVENTION

Accordingly, one object of the invention is to provide a novel impingement arrangement in which the roughness elements are optimized with regard to the manufacturing process and the thermal efficiency. Based on the above-mentioned known relief structures, both the geometrical form and its size and arrangement relative to the free jets are to be taken into account for this purpose.

According to the invention, this is achieved in an impingement arrangement of the type mentioned at the beginning by the defining features of patent claim 1. Favorable developments of the invention follow from the subclaims.

10002533-120501

In the field of turbomachines, from investigations relating to the cooling of curved blade leading edges, it is certainly known per se to design that side of the wall part which faces the impingement jet as a trough, an impingement jet striking the trough base perpendicularly. However, these known wall parts have a uniform wall thickness, so that ultimately the same principle is involved as the impingement cooling of a wall having plane surfaces on both sides.

The advantages of the novel measure may be seen, inter alia, in the fact that, as a result of the virtually isothermal surface, a high pin effectiveness is achieved and that there is also a high heat transmission at the areas which are not directed parallel to the wall to be acted upon by the impingement jets. In addition, simple and inexpensive production can be expected on account of the lack of sharp edges and small radii. The geometrical form is easy to produce and thus can readily be cast; it is tolerant of defects and permits large dimensional tolerances. As a result of the symmetry of the troughs, their arrangement does not depend on the incident flow by the deflected impingement medium. Finally, the novel troughs also result in low pressure losses.

In addition, the webs between the troughs may be provided with spacers to the jet-producing plate or, depending on the design of this plate, may even be used directly as spacers if the plate rests on the webs.

Finally, in addition to optimization of the thermal properties, the mechanical properties of the wall to be cooled are also improved by the novel measure.

#### BRIEF DESCRIPTION OF THE DRAWINGS

A more complete appreciation of the invention and many of the attendant advantages thereof will be readily obtained as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying

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drawings, wherein:

Fig. 1 shows a longitudinal section through an impingement-flow arrangement;

Figs 2a-c show various geometrical forms of troughs;

5 Fig. 3 shows a quadruple arrangement of troughs;

Fig. 4 shows a nested sextuple arrangement of troughs;

Fig. 5 shows a variant of the quadruple arrangement according to Fig. 3;

10 Fig. 6 shows a variant of the sextuple arrangement according to Fig. 4;

Fig. 7 shows an impingement-cooled gas-turbine blade;

Fig. 8 shows an exemplary embodiment with impingement tubes instead of impingement orifices;

15 Fig. 9 shows an exemplary embodiment with structured carrier.

20 DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the drawings, wherein like reference numerals designate identical or corresponding parts throughout the several views, only the elements essential for the understanding of the invention are shown, and the direction of flow of the media is designated by arrows, the impingement flow is designated below as impingement cooling, as can be used, for example, for cooling hot turbomachine components around which a flow occurs, such as gas-turbine blades or combustion-chamber walls.

25 The wall part to be cooled, for example, by means of cooling air 5 is designated by 3 in Fig. 1. This wall 3 is a plane wall around which a hot medium, designated by the arrows 6, flows on the outside. The cooling-air-side carrier 1 is also of corresponding plane design. In the case shown, it is fastened to the wall 3 at a uniform distance 20 by suitable means (not shown). The carrier has a plurality of impingement orifices 2 and may be conceived as a simple perforated

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plate.

On the inside, the wall 3 to be cooled is provided with a number of troughs 4 arranged next to one another. In the example, these troughs are in the form of spherical cups. The distance between the troughs is selected in such a way that a narrow web 7 is obtained between the adjacent trough walls. Compared with a plane design, the spherical-cup-shaped configuration of the wall to be cooled results in a considerable increase in the heat-transmitting area and thus in the heat flow.

In the example, that side of the wall part 3 which is remote from the impingement jet is of plane design. It goes without saying that this side remote from the impingement jet may just as easily be provided with a curvature, although the radius of curvature should then be very much larger than that of the spherical cup.

The wall part to be cooled is preferably cast in one piece together with the troughs. Irrespective of the manufacturing process, a structure of high strength is obtained. The structured area acted upon by the impingement jets - in relation to the basic thickness  $a$  of the wall 3 - contributes considerably to the rigidity of the entire system. On the one hand, this may lead to an advantageous reduction in the basic wall thickness  $a$ , if as low a mass of the system as possible is required. Or else, on the other hand, the fluid temperature on the hot side may be increased accordingly while maintaining the basic thickness  $a$  and a constant mechanical stress. Finally, while the basic thickness  $a$  and the temperature of the hot fluid are maintained, prolongation of the durability of the system can be expected due to the novel measure.

An impingement jet is provided for each trough, this impingement jet, which discharges from the impingement orifice 2, normally striking the trough base at least approximately perpendicularly. When it strikes, the impingement jet is deflected onto the

10002633-120501

remaining impingement area, i.e. the walls of the trough. The cooling medium, which is heated when flowing around the spherical cup, then flows off into the free space between carrier and wall part, the cross flow which occurs also helping to cool the webs 7.

Various further possible geometrical forms of troughs are explained in Fig. 2. Since the elements are of symmetrical construction, only one trough half is shown in each case.

10 Instead of the spherical cup according to Fig. 1, for the generation of which a circle is rotated about its diameter, Fig. 2a shows an ellipse shape. As in the case of the spherical cup, this shape is also generated by rotation of the corresponding segment about the axis U.

15 Fig. 2b shows a shape which is approximated to a shortened cycloid and has been generated by rotation of the corresponding segment about an axis U offset in parallel from the impingement-jet axis. It goes without saying that, in the case of this shape, the impingement jet must strike the inflection point exactly for full effectiveness.

20 Finally, Fig. 2c shows a trapezoidal trough which has a plane base and whose walls may be made straight or curved (as shown).

25 Irrespective of the trough geometry selected, a honeycombed structure is obtained in combination, to the individual elements of which a free jet is assigned in each case. The latter is positioned in such a way that its core, under the given boundary conditions -  
30 inter alia the cross flow of the outflowing cooling medium of adjacent elements - produces a stagnation point in the lower base region of the troughs. In this case, the axial position of the free jet can deviate from the rotation axis of the solid of rotation.

35 The geometry to be selected in each case is to influence the heat flow in such a way that the surface temperature decreases only marginally with increasing distance from the base and thus a virtually

constant heat flow can flow through the entire surface.

Since an adequate temperature difference is ensured everywhere as a result of this geometry, the entire surface can transmit heat. In addition, the heat transmission coefficient on the surface is roughly equal to that which would prevail on the base area without the trough. This in turn is in contrast to the known elements having areas running perpendicularly to the wall, in which elements a considerably reduced heat transmission coefficient is to be expected.

On account of the novel geometry of the troughs, a plurality of different arrangements are now possible and are to be selected with a view to the desired heat transmission and/or the tolerable pressure losses.

In relation to the cross flow in the region of the base, two arrangements can be differentiated in principle.

The impingement orifices 2 and the troughs 4, in combination, may either be arranged in a row according to Fig. 3 or they may staggered relative to one another, for example by half a spacing according to Fig. 4. This results in arrangements which are either square or hexagonal, as the broken lines in Figs 3 and 4 respectively show.

The troughs 4 are preferably arranged at the intersections of these broken lines. As Fig. 3 shows, in the arrangement in a row, troughs which are directly adjacent are arranged without intermediate spaces, i.e. without webs. Nonetheless, relatively large webs 7 are formed in this embodiment in the center of in each case four troughs. Spacers to the carrier may be provided on these webs, in which case these spacers may also be cast integrally with the wall 3.

In the staggered arrangement according to Fig. 4, six symmetrical elements are nested one inside the other with a juxtaposed sextuple arrangement. Here, it can be seen that, given the same trough size, the surface is enlarged compared with the arrangement

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according to Fig. 3 in so far as the webs, now formed between three troughs each, assume considerably smaller dimensions.

The arrangement according to Fig. 5 corresponds in its geometry to that of Fig. 3. The size of and the mutual distance between the impingement orifices 2 are selected to be the same. On the other hand, the diameter D of the troughs has been increased, which leads to the intersecting of adjacent troughs and to smaller webs 7. This solution can have production-related advantages and, depending on the choice of diameter, can lead to shallower troughs.

The arrangement according to Fig. 6 corresponds in its geometry to that of Fig. 4. The size of and the mutual distance between the impingement orifices 2 are again selected to be the same. On the other hand, the diameter D of the troughs has been increased, which leads to the intersecting of adjacent troughs and to extremely small webs. It will be seen here that, from a certain trough diameter, no more webs at all are formed.

In Fig. 7, a gas-turbine blade 16 is shown as an example of a component to be cooled. The carriers with the impingement orifices 2 are conceived as more or less tubular inserts 17A, 17B and 17C and are arranged in the hollow interior of the blade. These inserts as well as the blade wall provided with the troughs 4 may be designed as a casting. They may likewise be designed as a pressure-bearing structure for internal pressures, which may be up to twice the pressure prevailing in the actual impingement zone.

In the case of a guide blade, the inflow of the cooling medium into the inserts takes place as a rule from the blade root toward the blade tip. The impingement orifices 2 and the troughs 4 are staggered over the blade height and the blade circumference at the requisite distance apart. Flow may occur through the inserts 17A-C individually or in series.

The gaseous or vaporous cooling medium may be

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circulated in closed circuit in the plurality of inserts, i.e. it is drawn off again via the blade root after cooling has been carried out. However, the cooling medium flowing off from the cooled wall parts may discharge from the blade into the flow duct. This preferably takes place at that point of the blade at which the lowest external pressure prevails. As a rule, therefore, the cooling medium will be made to discharge at the trailing edge 18 of the blade.

Fig. 8 shows an exemplary embodiment in which the carrier is likewise sheetlike and is provided with a multiplicity of impingement tubes 21, which are equidistant here and are arranged in rows. Their inlet 22 corresponds to an impingement orifice and is flush with the carrier surface. The impingement tubes have a conical internal passage narrowing constantly in the direction of flow. The narrowest cross section of the impingement tubes thus lies at the mouth 23. The impingement tubes are directed with their mouth 23 perpendicularly toward the wall part to be cooled. The mouth is located at the impingement distance 25 from the wall. In the example, the ratio of this impingement distance to the narrowest diameter of the impingement tubes is about 1. It can be seen that the cooling air, deflected after the impingement, can flow off into the free intermediate spaces 27 between the impingement tubes without disturbing adjacent impingement jets in the process. The closed dimension of the intermediate space is given by the length of the impingement tubes when the latter are oriented perpendicularly. In contrast to the cooling-air jets which are produced via a perforated plate, this solution offers the advantage that the ratio of jet distance to jet diameter may be formed freely, and this ratio may quite easily extend over a range of 0.1 to 4.

The troughs have hitherto always been considered to be rotationally symmetrical bodies which have been generated by rotation of the corresponding section through 360°. In contrast, it is of course also

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possible to design the troughs in a channel shape, although the surface enlargement turns out to be somewhat smaller than with rotationally symmetrical troughs. To produce a channel, the corresponding  
5 section is not rotated about an axis U but is displaced along a preferably straight axis U. In this way, longitudinal channels having a circular, elliptical or trapezoidal shape are obtained at the area to be cooled. In this configuration, the stabilizing effect  
10 of the surface-enlarging structure occurs in a defined direction. In this solution, the impingement jets are likewise to strike the base of the channel. A certain number of impingement jets in the longitudinal extent of the channel will be provided here, in which case,  
15 according to the requisite cooling capacity, attention is to be paid to the impingement-jet spacing to be selected. In this case, it has been found that a defective arrangement, for example related to production, of the impingement jets has only a marginal  
20 effect on the effectiveness of the entire system.

As already mentioned above, the simplest case for the carrier 1 is a plane perforated plate. According to Fig. 9, however, a perforated plate having spherical-cup-like depressions 26 may also be used. The  
25 depressions in each case contain the impingement orifices 2, and it can be seen that this solution provides a simple means of influencing the impingement distance 25. In the event of the troughs being designed in a channel shape, it is advisable to also configure  
30 the depressions 26 as channels. The latter need not necessarily run in the same direction as the troughs. They may run at any angle between  $0^\circ$  and  $90^\circ$  to the trough direction or to the direction of the cooling flow 5. The intermediate spaces 27 present between the  
35 depressions may thereby be utilized for the specific discharge of the cooling medium. In addition, the different direction offers the possibility of supporting the channel-shaped depression 26 directly on the webs 7 of the trough (not shown).

The invention is of course not restricted to the examples shown and described. It goes without saying that, depending on requirements, the number and spacing of the impingement orifices 2 or impingement tubes 21 as well as the length and shape of the latter can be optimized from case to case. The invention also sets no limits to the selection of the cooling medium, to its pressure and to its further use after the cooling activity.

Finally, the person skilled in the art will recognize that the invention can be used not only for the purpose of cooling wall parts of machines, apparatus or plants in general but can just as easily be used for heating them. Examples for such a use of the heating of surface areas are the drying of paper, the melting and bonding of plastics, the deicing of aircraft wings, etc.

Obviously, numerous modifications and variations of the present invention are possible in light of the above teachings. It is therefore to be understood that, within the scope of the appended claims, the invention may be practiced otherwise than as specifically described herein.

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